



Meteoroid-Induced Anomalies on Spacecraft

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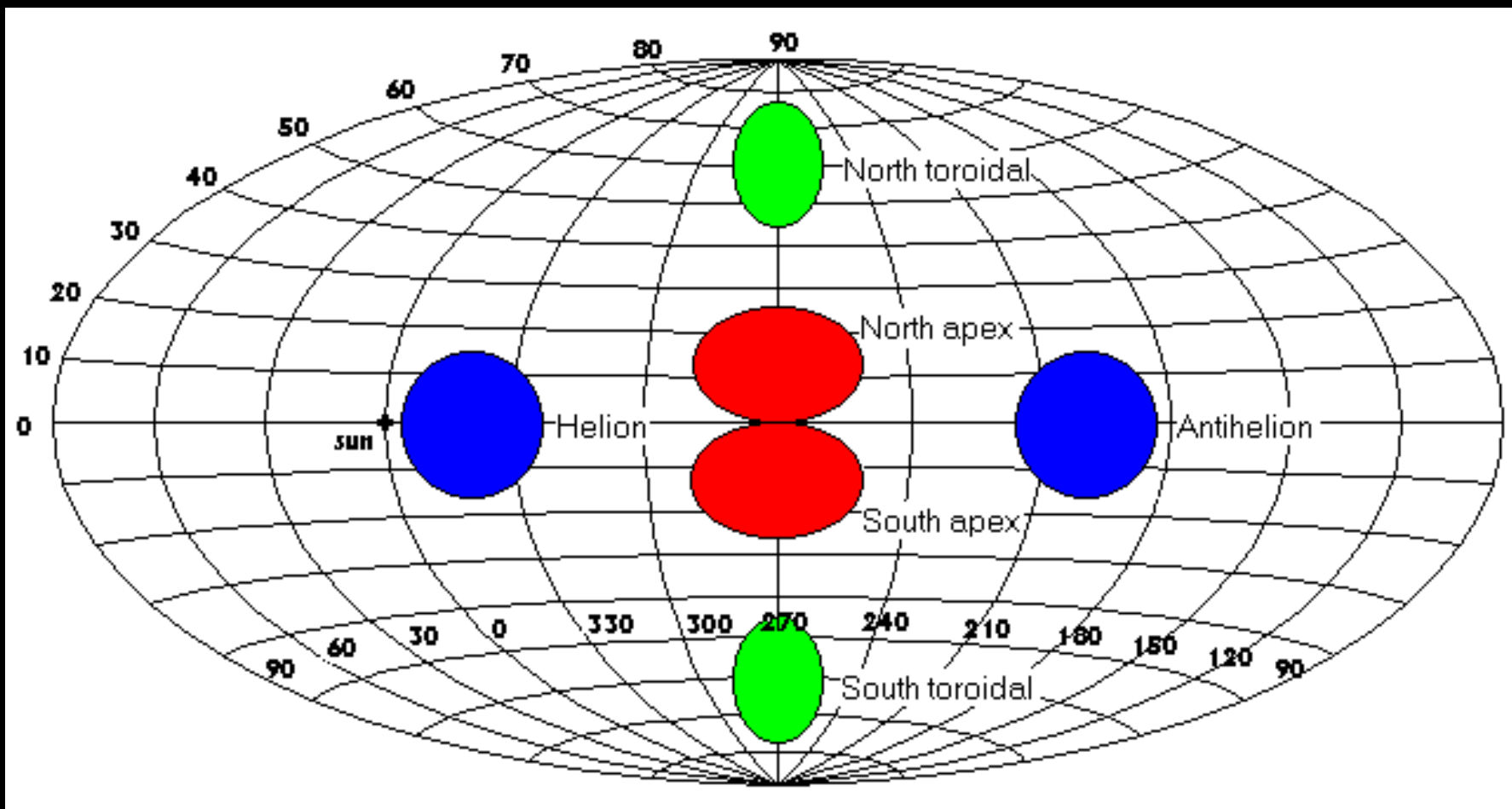
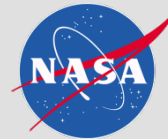
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Overview

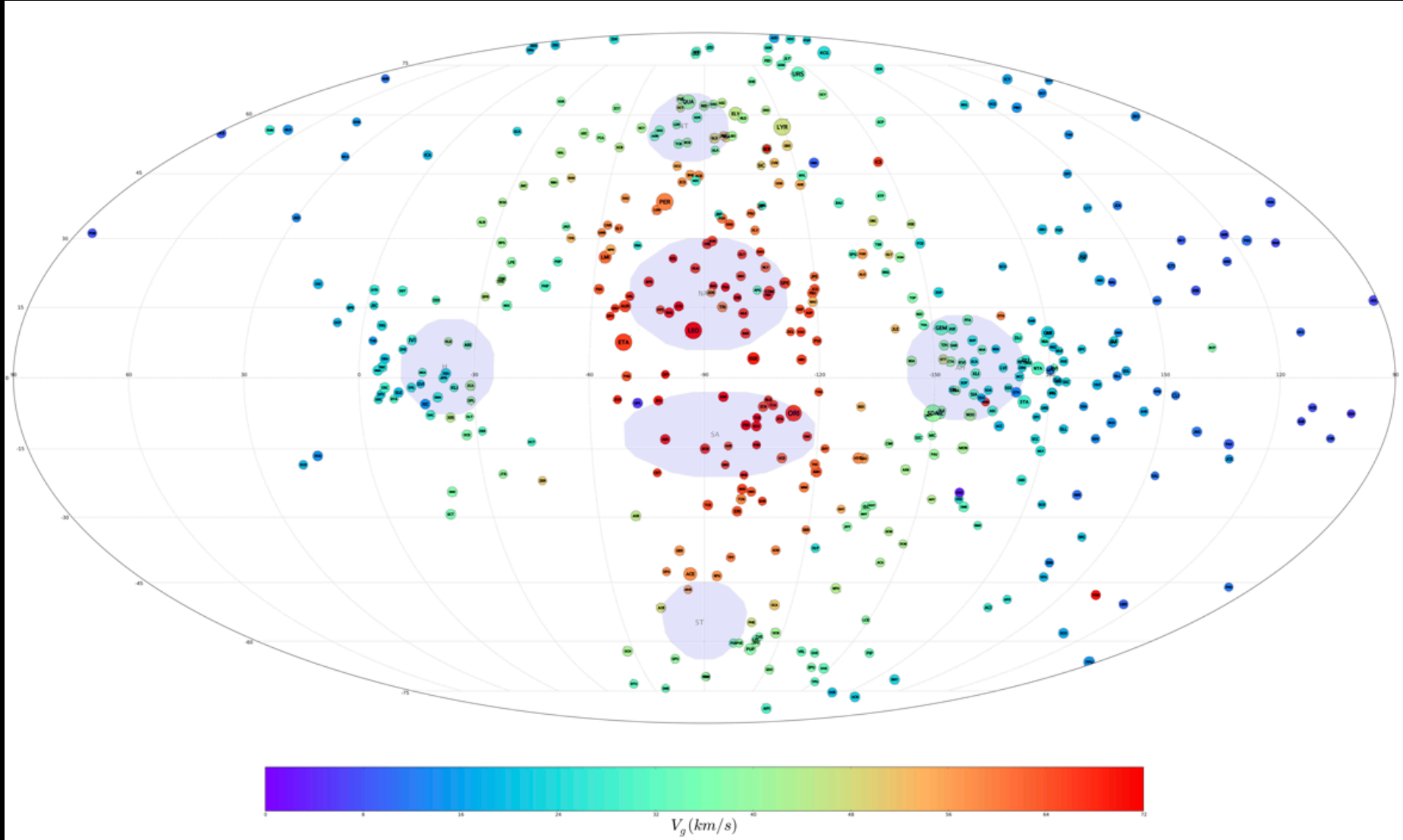


- Sporadic meteoroid background is directional (not isotropic) and accounts for 90% of the meteoroid risk to a typical spacecraft.
- Meteor showers get all the press, but account for only $\sim 10\%$ of spacecraft risk.
 - Bias towards assigning meteoroid cause to anomalies during meteor showers.
- Vast majority of meteoroids come from comets and have a bulk density of $\sim 1 \text{ g cm}^{-3}$ (ice).
- High speed meteoroids ($\sim 50 \text{ km s}^{-1}$) can induce electrical anomalies in spacecraft through discharging of charged surfaces (also EMP?).

Sporadic Directionality



Meteor Shower Radiants

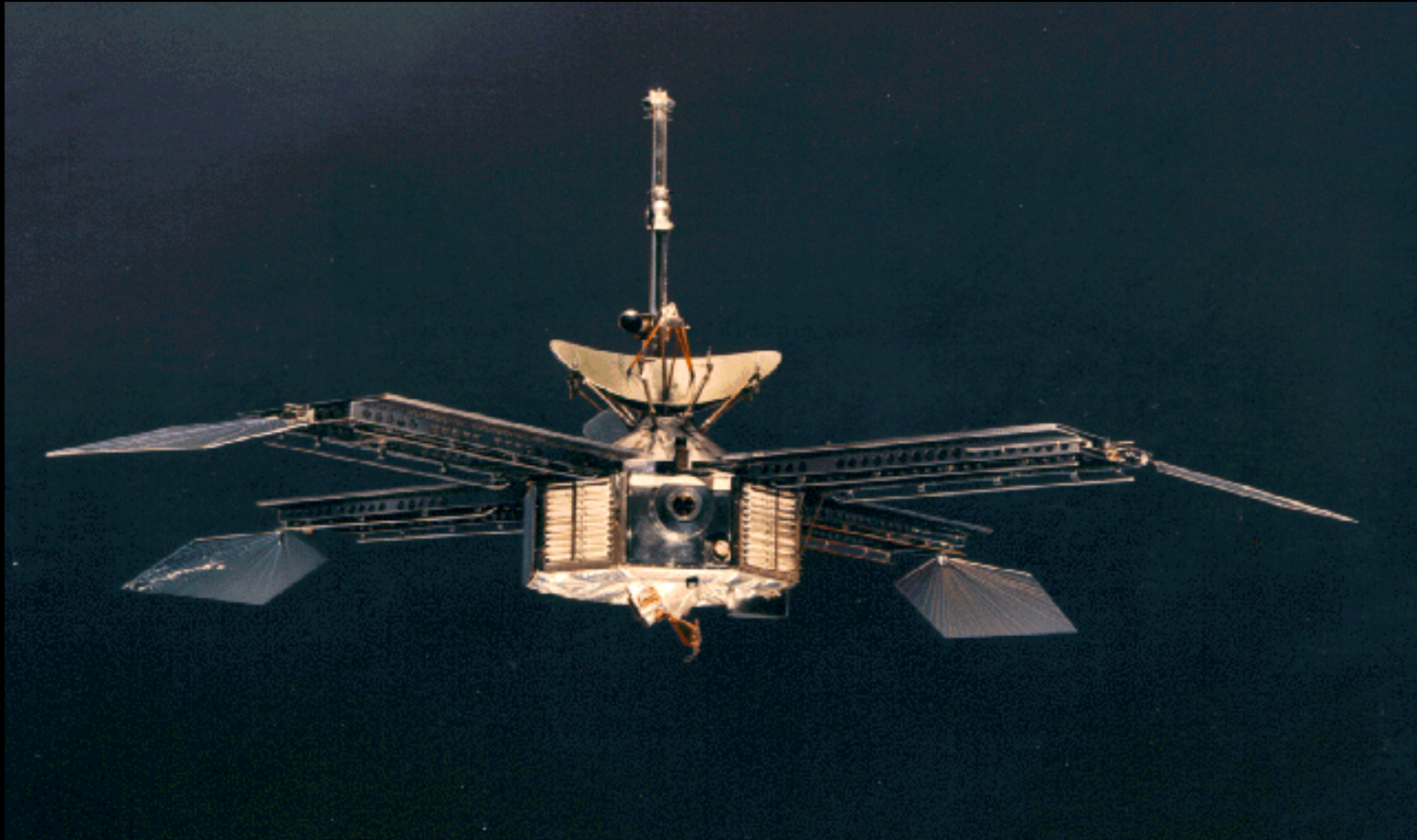


Could it be a meteoroid?



- Are the anomaly characteristics consistent with a particle impact?
 - Sudden change in attitude most common.
- Was there a meteor outburst or storm at the time of the anomaly?
 - If yes, was the shower radiant visible from the spacecraft?
 - If yes, did the affected surface “see” the shower radiant?
 - If yes, shower impact possible.
- Compare meteoroid (sporadic + shower) flux to orbital debris flux at spacecraft location to establish likelihood.
 - If affected surface is sun-fixed, must use a directional meteoroid model to compute flux.

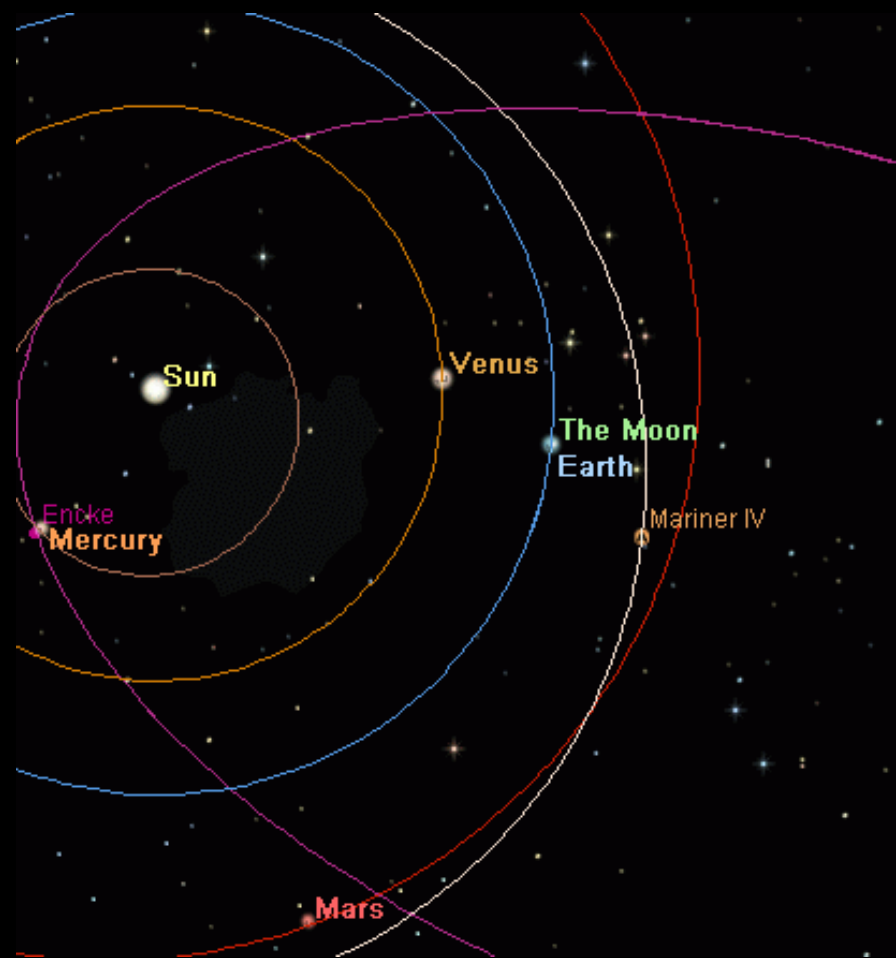
Mariner IV



- Launched 28 November 1964; flew by Mars on 14-15 July 1965.
- From *Astronautics and Aeronautics*, 1967, pg. 270-271, September 15 entry:

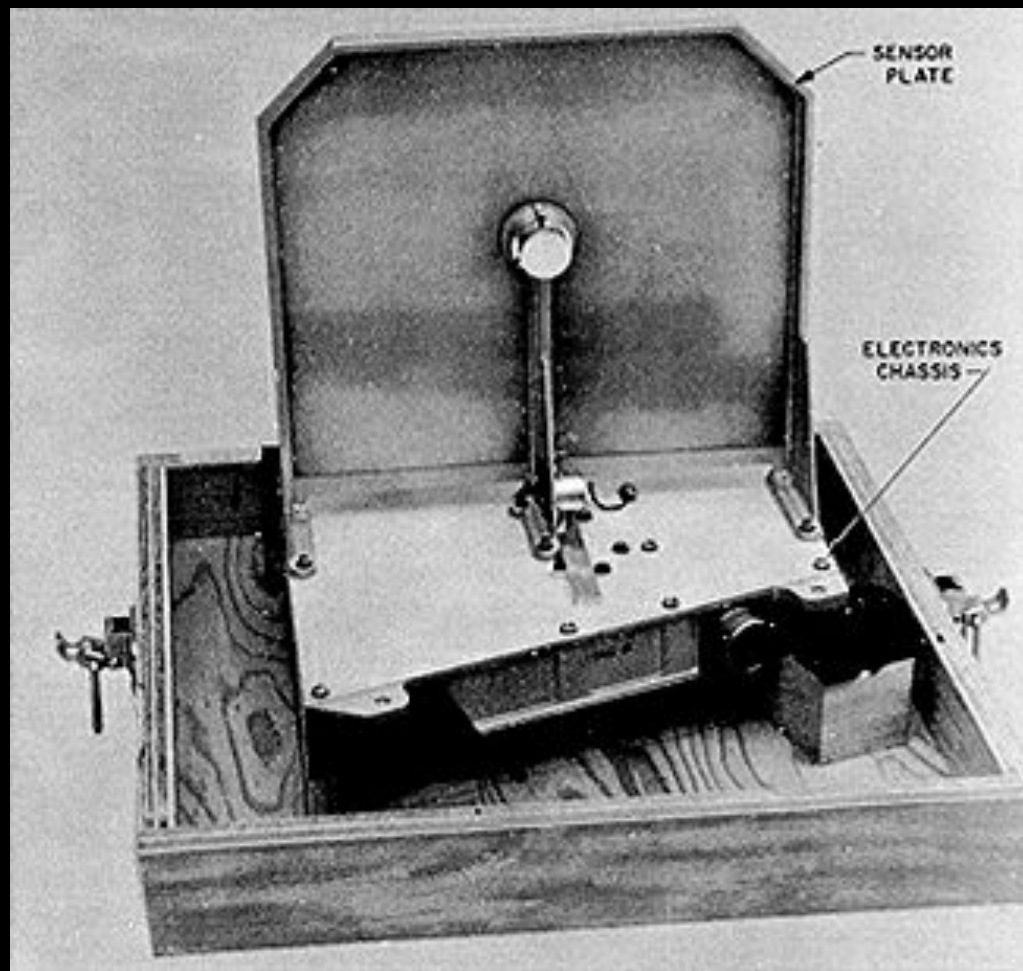
“Mariner IV, launched Nov. 28, 1964, survived apparent micrometeoroid shower. Spacecraft’s cosmic dust detector registered 17 hits within 15 min, while Mariner IV traveled between orbits of earth and Mars. Spacecraft was 29.6 million miles from earth and had traveled about 1.4 billion miles in its 1,020 days of flight. Micrometeoroid shower had caused temporary change in spacecraft’s attitude but no loss of power. Scientists concluded, from one-degree temperature drop inside spacecraft, that only the thermal shield was damaged. Within about a week, spacecraft was operating normally without any apparent effect from incident...”

- Position of spacecraft at encounter:
Heliocentric distance: 1.273 AU
Ecliptic Longitude: 343.6 degrees
Ecliptic Latitude: 2.25 degrees N.
- Spacecraft torqued about roll axis;
thermal insulation ripped away.
- Report estimates that the spacecraft
was struck by 2 or 3 orders of
magnitude more particles than the
17 recorded by the dust instrument
(Mariner IV is only U.S. spacecraft
sent to Mars with meteoroid
detector).
- Impact rates this high have only
been measured near comet nuclei
(Halley).



Number of hits during shower was 1500x higher than mission average, and only 60x lower than Giotto's hit rate at closest approach to Halley.

Impacts suffered by M4 may have resulted from a passage through a cometary meteoroid stream or the debris of or perhaps even the "coma" of an undetected dead or nearly-dead comet.



Mariner IV Cosmic Dust Detector
22.1cm on a side, 0.8 mm thick

Olympus



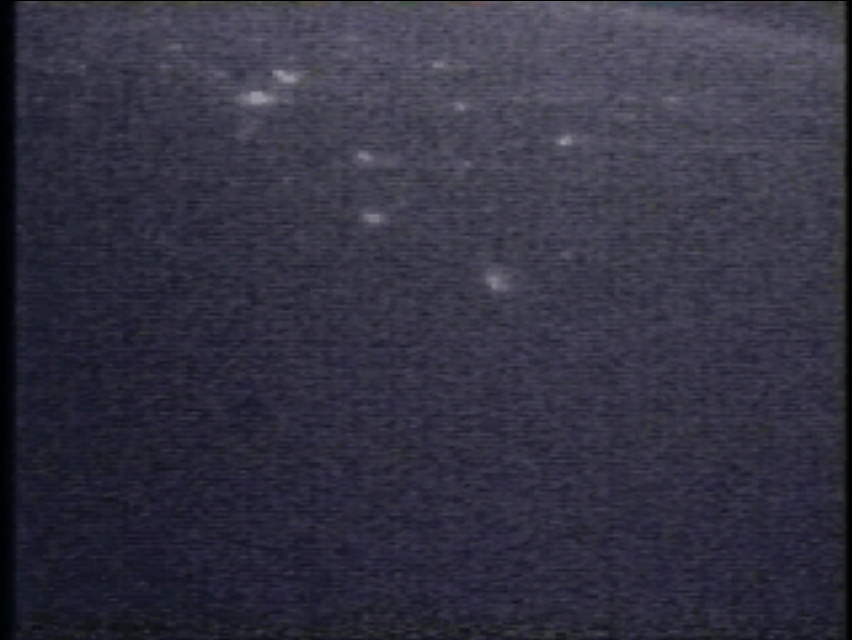


- Technology demonstration satellite - launched 12 July 1989; largest civilian comm satellite built up to that time.
- South solar panel stopped tracking the Sun in January 1991 (particle impact?).
- 19 June 1991– attitude control issue; incorrect commands uplinked from ground resulted in tumbling and drift off station. Vehicle recovered and put back into service at 19W on 7 August 1992.

The 1993 Perseids



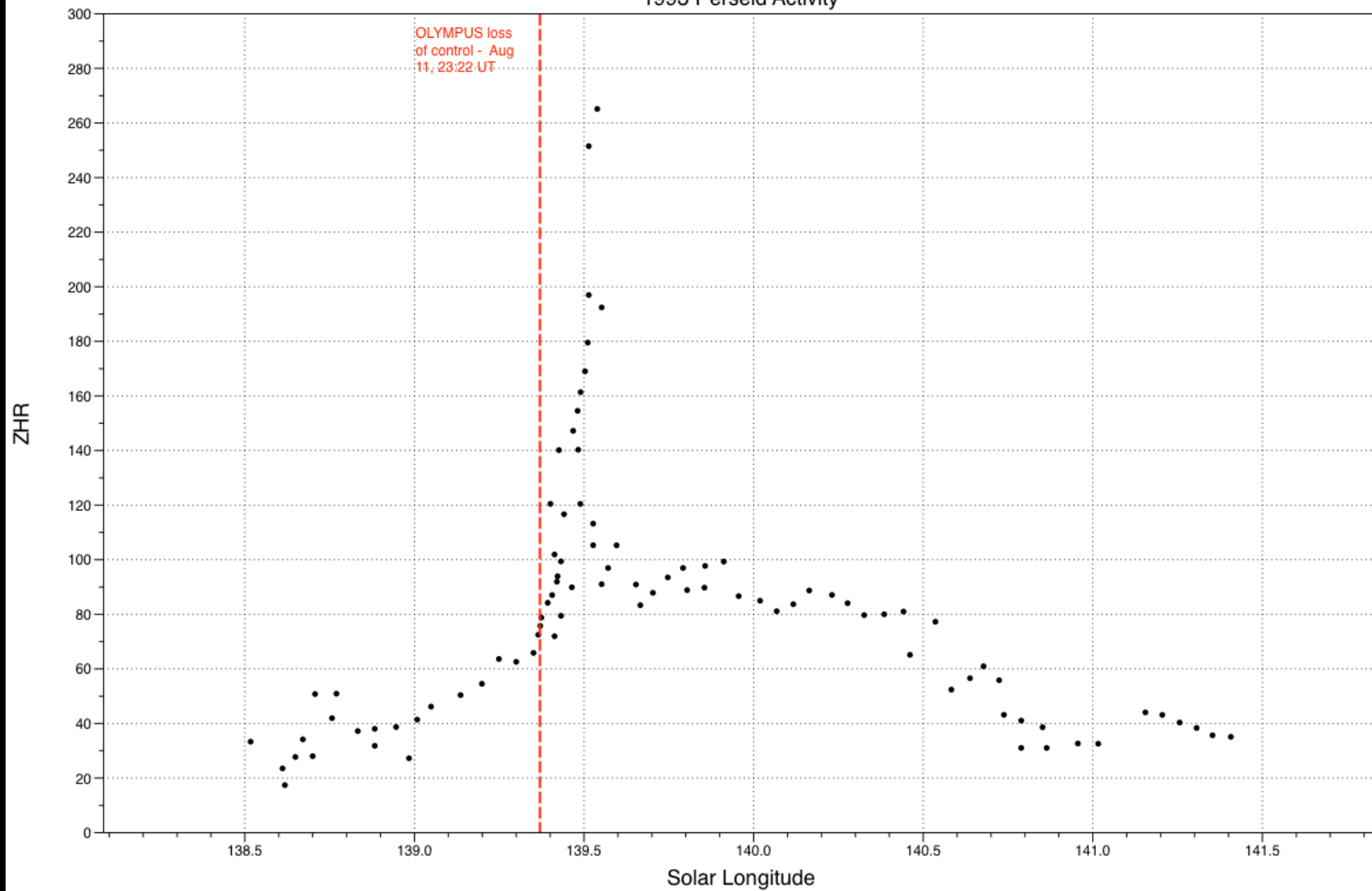
- Before modern shower forecasting techniques – no one knew what to expect.
- Parent comet (Swift-Tuttle) had just passed perihelion in December of 1992, so there were many “predictions” of a major outburst.
- Launch of STS-51 (Discovery) delayed until after shower peak – only Shuttle launch ever delayed because of a meteor shower.
- An outburst did occur, with meteor rates exceeding 250 per hour around 3:30 UTC on August 12.



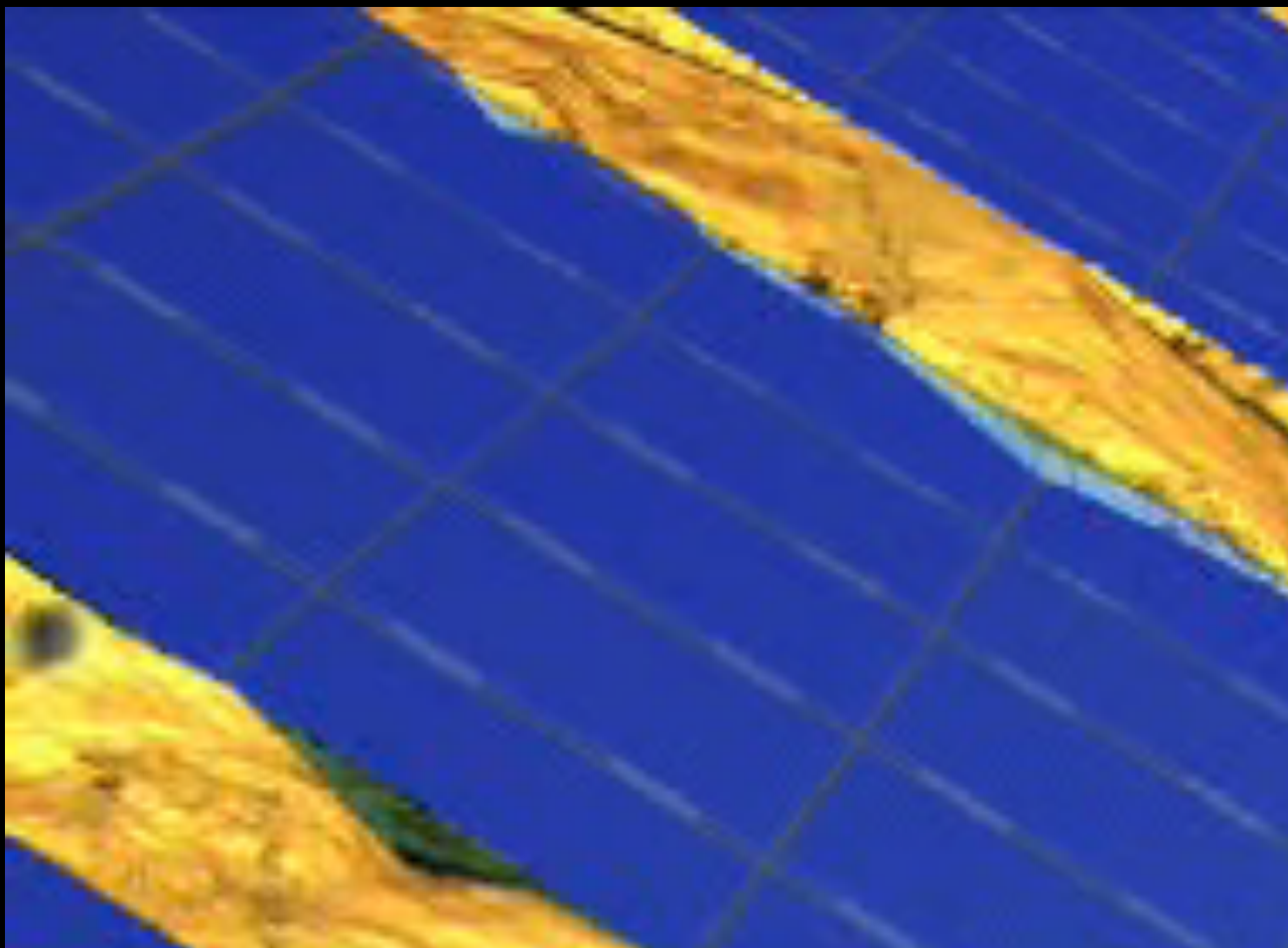
STS-105, August 2001

- Olympus roll gyro stops at 23:32 UTC August 11. Spacecraft enters ESA mode and fails to acquire the Sun.

1993 Perseid Activity



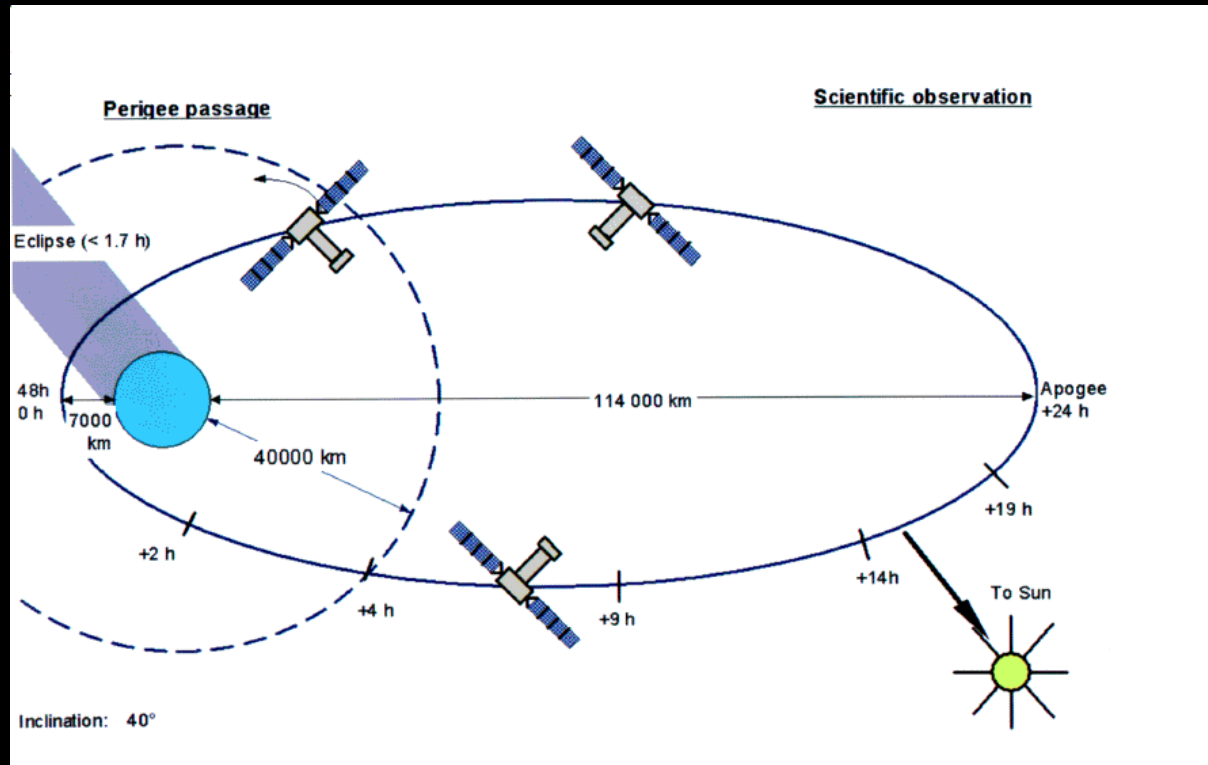
- Attempts to recover spacecraft exhausted most of remaining fuel, making it impossible to return the vehicle to service. Mission was terminated August 12, and the spacecraft was moved into a disposal orbit 200 km below GEO.
- ESA anomaly investigation attributed the failure to a Perseid strike on the south solar array.
 - South array had 8.5 m^2 of area exposed to the stream.
 - There was a possible conducting path to the gyro through the spacecraft umbilical.
 - Ground hypervelocity tests showed plasma generated by a meteoroid strike to be proportional to $v^{3.5}$.



XMM-Newton



- ESA X-ray observatory
- Launched on 10 December 1999; still operational



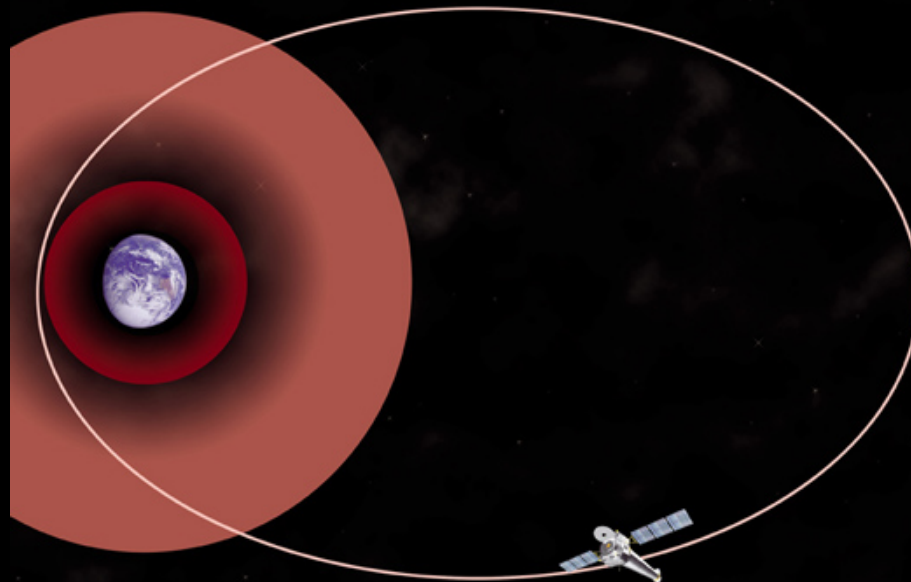


- On 17 September 2001 at 23:31 UTC, a diffuse light was observed in a single frame taken by the MOS1 camera.
- Immediately after the event, 27 new bad pixels were noted.
 - Anomaly investigation concluded meteoroid impact.
 - Camera was observing an X-ray object located in the same direction as the south Toroidal sporadic source.
- XMM-Newton has taken other hits: 15 October 2000, 12 August 2002, and 9 March 2005.
- The 2005 hit destroyed the CCD6 segment of the MOS1 camera.
- XMM-Newton's multiple cameras have an estimated 22% per annum impact probability for the ensemble.

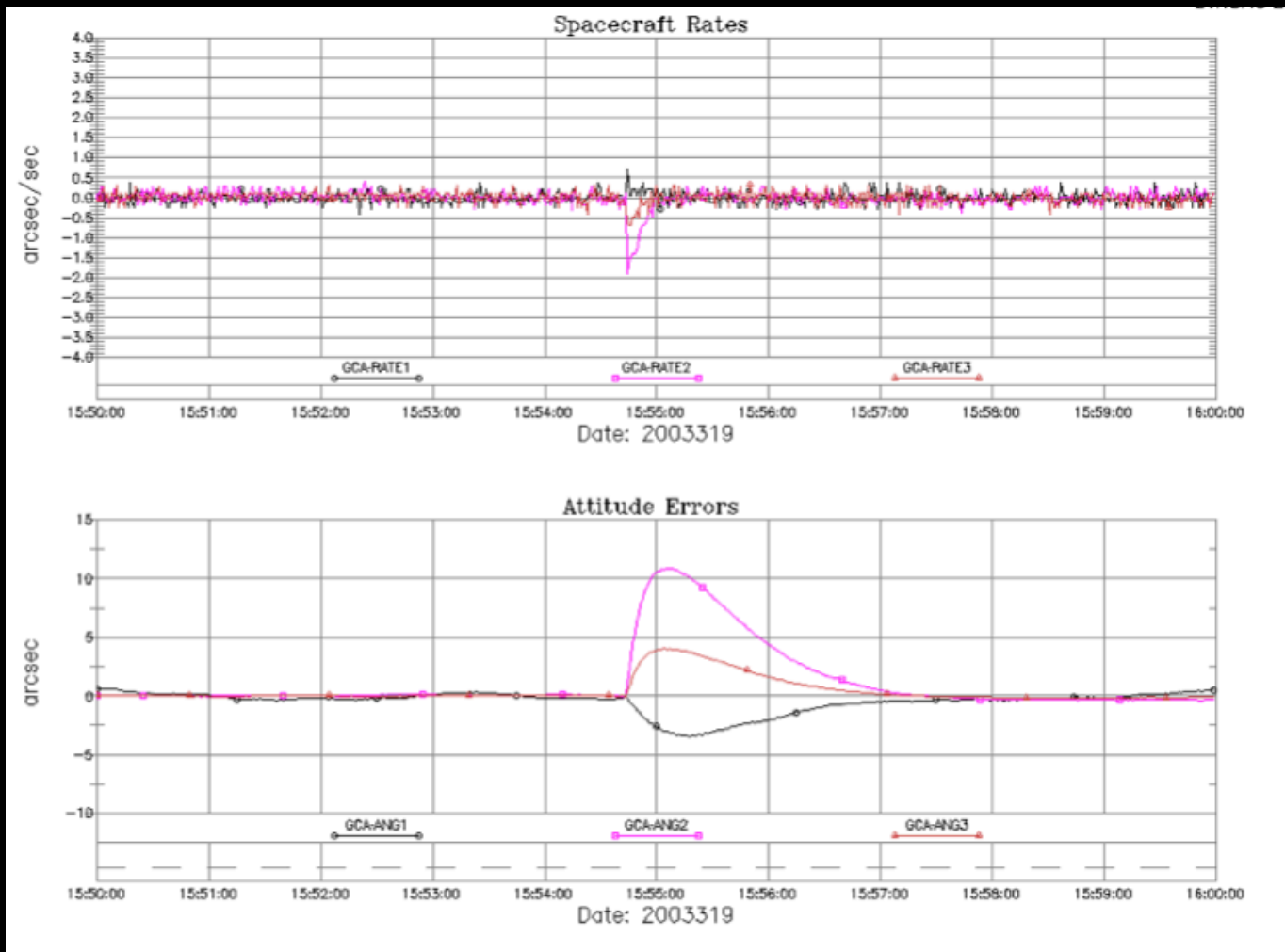
Chandra

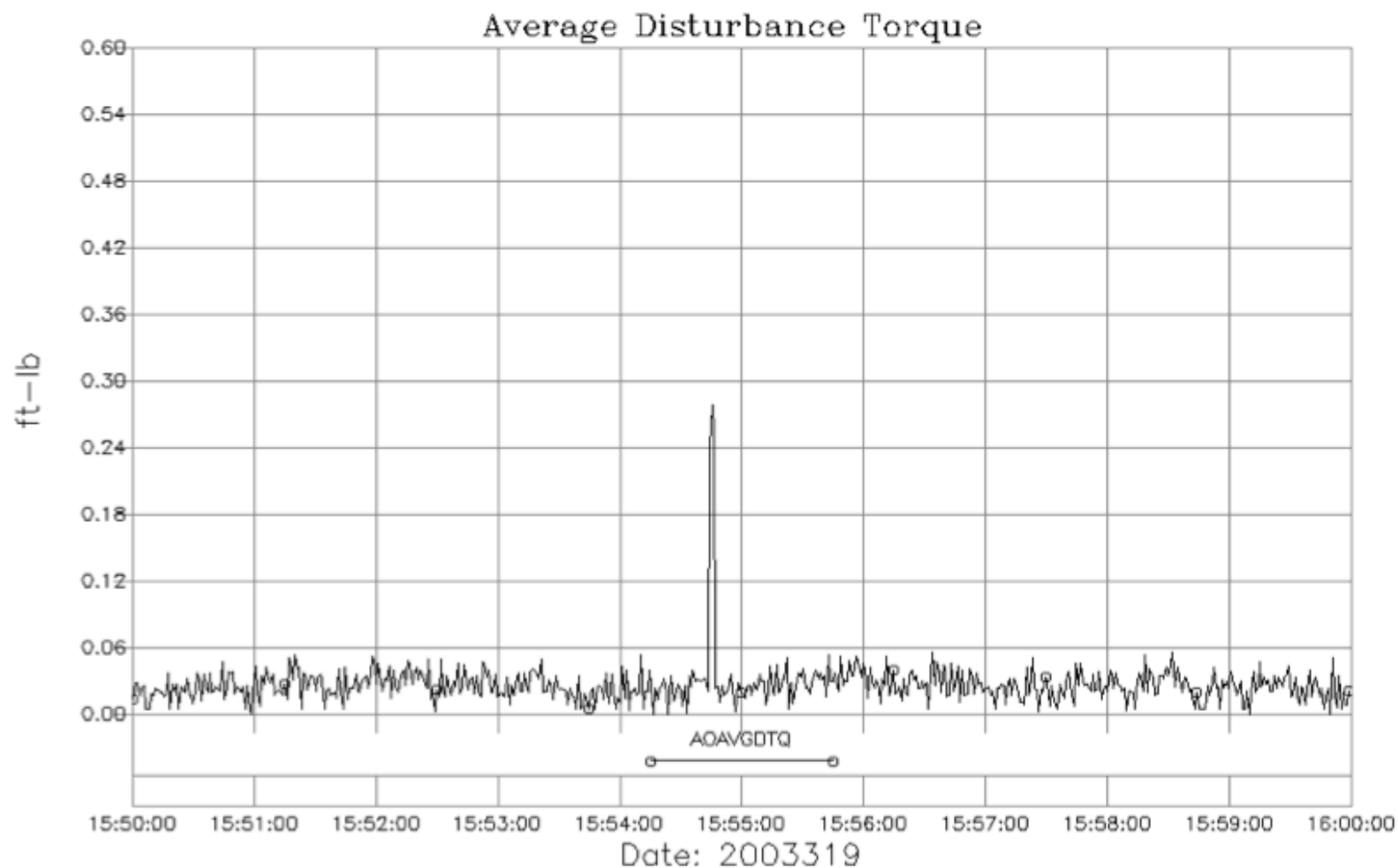


- NASA X-ray observatory.
- Launched 23 July 1999; still operational.
- Perigee: 16,000 km Apogee: 133,000 km



- Disturbance in pointing stability just before 4:00 UTC on 15 November 2003.





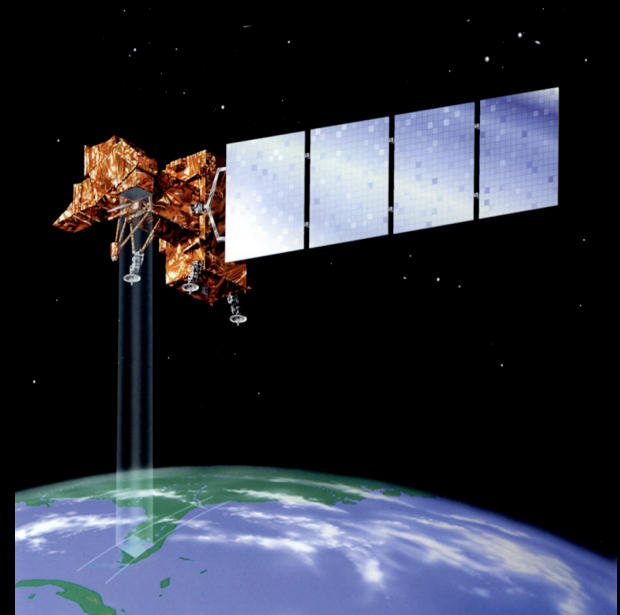


- Program computed that an impact by a 1 mm Leonid could account for observed displacement – other causes ruled out.
 - Impact out near apogee.
- However, there was no Leonid storm in 2003, and the impact occurred well away from the observed shower maxima. At time of impact, meteor rates were <20 per hour.
- Measurements of the sporadic flux shows that it was 2 orders of magnitude larger than the Leonid flux at the event time.
 - Leonid radiant is located within the north Apex sporadic source, which has an average speed of 55 km s^{-1} .
 - Fluxes would indicate that an impact by a north Apex sporadic is 5 times more likely than that from a Leonid.

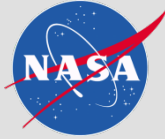
Landsat 5



- What: Remote sensing satellite.
- Event: Struck by a Perseid near the time of the shower peak on August 13 2009.
- Consequences:
 - Gyro temporarily failed; spacecraft began tumbling.
- Outcome: Normal operations restored by August 17.

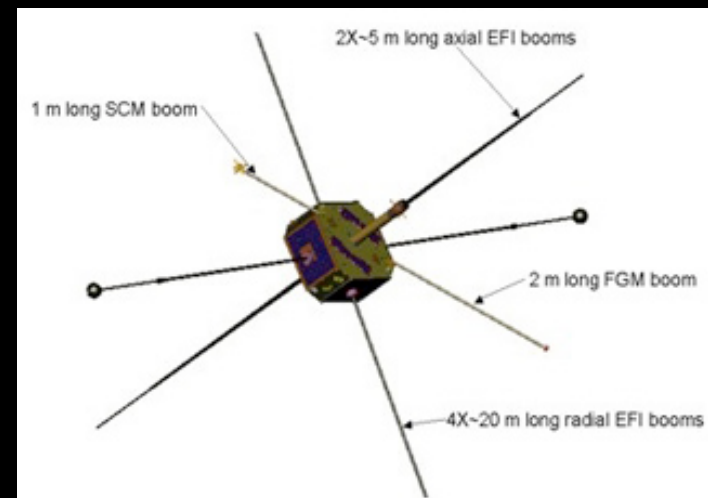
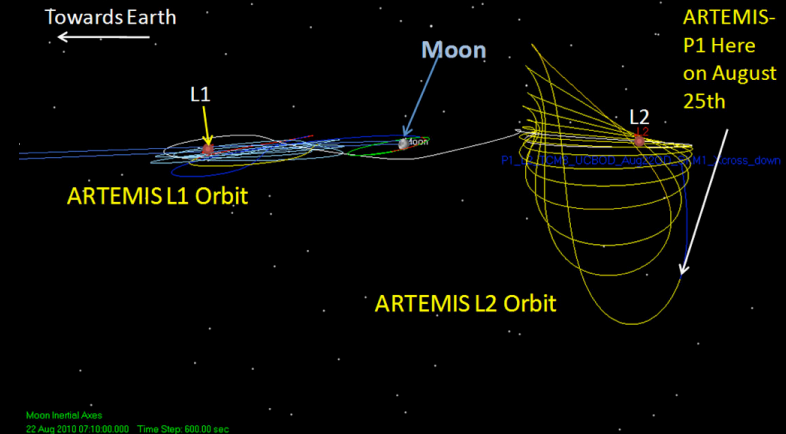


Artemis P1



- What: NASA Science satellite.
- Event: Struck by a meteoroid on 14 Oct 2010.
- Consequences:
 - Sphere 2 cut away
- Outcome: Normal operations restored almost immediately.

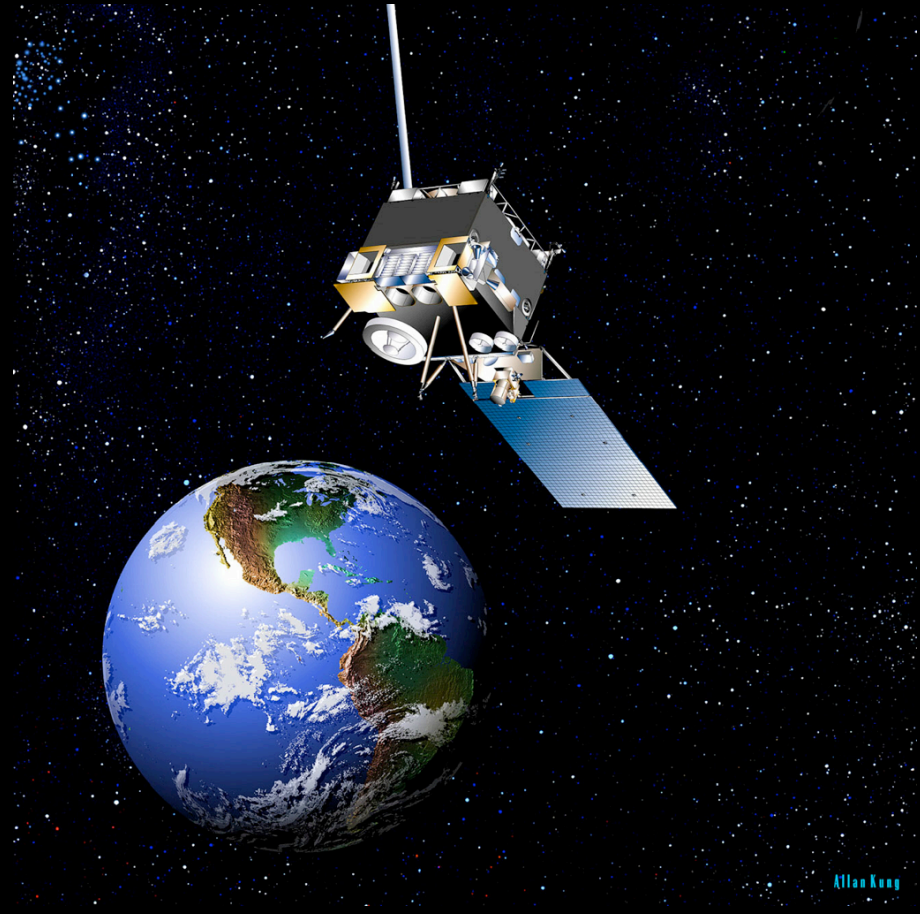
ARTEMIS-P1 Spacecraft's Orbit – Side View



GOES 13



- What: USG weather satellite.
- Event: Struck by a Helion meteoroid on 22 May 2013.
- Consequences:
 - Attitude drift of 2° per hour from nadir
 - Spacecraft entered safe mode
- Outcome: Normal operations restored 7 days later.



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